Searching for Habitable Environments

Science Perspectives for Candidate Mars Mission Architectures for 2016-2026

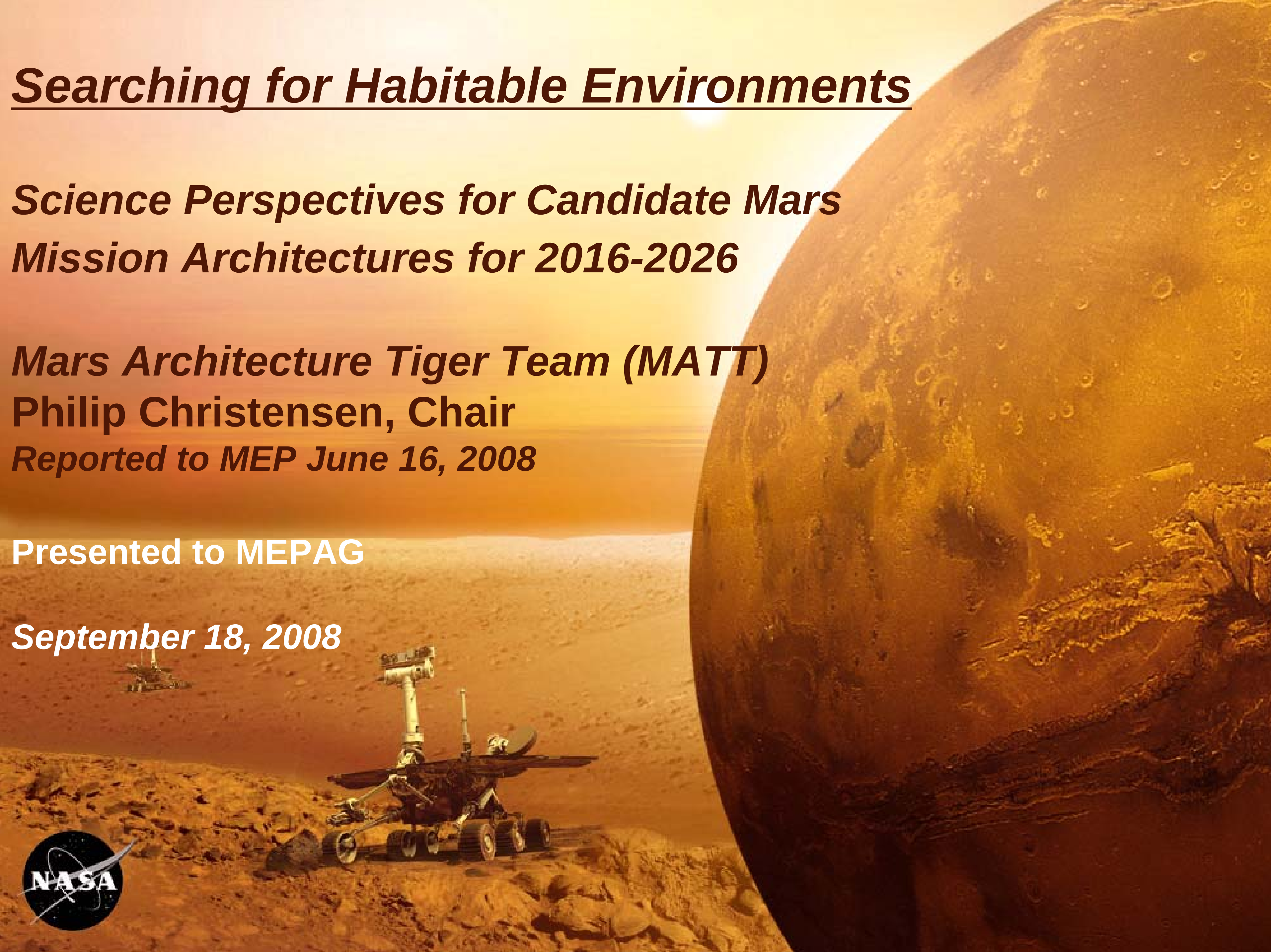
Mars Architecture Tiger Team (MATT)

Philip Christensen, Chair

Reported to MEP June 16, 2008

Presented to MEPAG

September 18, 2008



MATT Study-2: Participants

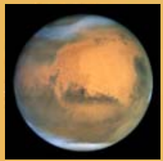
Phil Christensen *(ASU, Chair)*
Lars Borg *(ND-SAG Co-Chair)*
Wendy Calvin *(MSO SAG Chair)*
Mike Carr
Dave DesMarais *(ND-SAG Co-Chair)*
Francois Forget
Noel Hinners
Scott Murchie *(MSS SAG Chair)*
Jack Mustard *(MEPAG Chair)*
Lisa Pratt
Chip Shearer *(CAPTEM)*
Mike Smith *(MSO SDT Chair)*
Steve Squyres
Christophe Sotin

NASA HQ
Lisa May
Michael Meyer *(MEP Lead Scientist)*

JPL Mars Office
Dave Beaty
Jan Chodas
Frank Jordan
Richard Mattingly
Rich Zurek

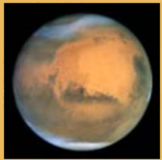
MATT Study-2: Context

- **Key Directives for MATT-2**
  - Focus on a program that achieves fundamental science and addresses the highest priority goals for Mars Exploration; do not worry about telecom infrastructure
  - Assume there will be a 2013 Scout mission selected from the current competition
  - Assume the MEP budget is sustained at some rate (~$550M/yr beginning in 2010) and trades can be made in peak spending years
- **MATT-2 study builds on earlier work: NRC and MEPAG**
- **NRC:**
  - NRC Reports and Decadal Survey
    - Major Milestone: NRC Special Committee (drawn largely from the NRC Committee on Evolution and Life) and Report: *An Astrobiology Strategy for Exploration of Mars*
- **MEPAG:**
  - MEPAG Goals, Objectives,Investigations documentation
  - Mars Next Decade (ND) and Mars Strategic Science (MSS) SAGs
  - MATT-1 Discussions
  - Involved the JPL Mars Office Advanced Studies Team regarding mission costs and feasibility



MATT Activities

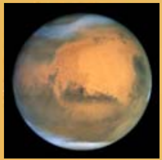
- **MATT focused on the theme "Seeking Habitable Environments" for the 2016-2026 time period**
  - This theme provides near-term focus for the general effort to understand "Mars as a System" for a planet where life may have developed
- **MATT proceeded as follows:**
  - **Distilled mission science goals for 2016-2026.** These goals:
    - Are consistent with the "Seeking Habitable Environments" theme
    - Are responsive to the NRC/Decadal Survey Priorities
    - Address MEPAG Goals, Objectives and Investigations
  - **Identified mission "building blocks" that address the mission science goals for the decade**
    - Includes: MSR, MPR, MSO, NET, Scout
      - Mission "blocks" identified at a high level--see following slides
  - **Developed a set of guidelines to determine mission sequences**
    - Mission sequences considered in order of when MSR Lander would launch
      - MSR launches are high priority science, but budget driven



MATT Study-2: Expected Outcomes

The MEP mission architectures developed by MATT for 2013-2026 strive to achieve the following objectives:

- Investigate the physics, chemistry, and dynamics of the upper atmosphere, the effects of solar wind and radiation, and the escape of volatiles to space - **Addressed by 2013 Scout**
- Explore a diversity of surface environments using rovers with sample acquisition, analysis, and caching capabilities
- Determine the composition and structure of the current atmosphere
- Investigate the deep interior using a network of landed geophysical experiments
- Return carefully selected and well-documented samples from a potentially habitable environment to Earth for detailed analysis
- Respond to new discoveries through focused missions



MEP Building Blocks for 2016-2026 (1 of 2)

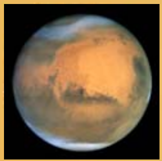
MATT identified these potential mission building blocks to address the key scientific objectives for 2016-2026:

- **Mars Sample Return Lander (MSR-L) and Orbiter (MSR-O):**
  - Two flight elements: Lander/Rover/Ascent Vehicle & Orbiter/Capture/Return Vehicle
  - High-priority in NRC reports and Decadal Survey; must address multiple science goals with samples meeting the minimum requirements set out in the ND-SAG report
- **Network (NET):**
  - 4 or more landed stations arrayed in a geophysical network to characterize interior structure, composition, and process, as well as surface environments
  - Meteorological measurements are leveraged by concurrent remote sensing from orbit
  - High-priority in NRC reports and Decadal Survey

MEP Building Blocks for 2016-2026 (2 of 2)

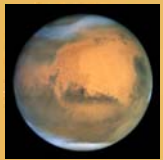
MATT identified these potential mission building blocks to address the key scientific objectives for 2016-2026 (cont.):

- **Mars Science Orbiter (MSO)**
  - Atmospheric composition, state, and surface climatology remote sensing plus telecom
  - Science Definition Team formed and report given to MEP
- **Mars Prospector Rover (MPR, also called Mid-Range Rover)**
  - At least MER-class rover deployed to new water-related geologic targets
  - Precision landing (<6-km diameter error ellipse) enables access to new sites
  - Conducts independent science but with scientific and technical feed-forward to MSR
  - As a precursor, this can demonstrate feed-forward capabilities for MSR and opens the possibility for payload trade-offs (e.g., caching and cache delivery) with MSR Lander
- **Mars Scout Missions (Scout)**
  - Competed missions to pursue innovative thrusts to major missions goals



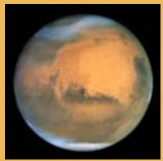
Option: Network

- **Concept: ≥ 4 Landed Stations Arrayed in a Seismic Network**
- **Goals**:
  - Characterize interior structure, composition and processes
  - Elucidate evolution of the interior over time and role in Mars climate history
  - Advance the comparative study of planetary formation and evolution
  - Characterize local meteorology and provide baseline for orbital climate measurements
    - Long-lived surface measurements
    - Substantially enhanced by concurrent orbital remote sensing of the atmosphere
  - **Highest priority after sample return in NRC reports / Decadal Survey**
- **Approach:**
  - Conduct interior measurements, particularly of seismic signals
  - Other goals: Heat flow, magnetics
  - Does not require precision landing
  - Significantly enhanced by Orbiter relay for telecom
  - Significantly enhanced by long-term (≥ 2 Mars years) observing period
  - Could easily be part of an international collaboration
- **Issues:**
  - Unknown signal character complicates payload design
    - A precursor demonstration may be needed to motivate (ExoMars?)
  - Requires new EDL design for implementation (I.e., cannot use MER/MSL)



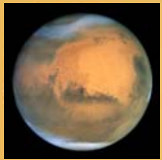
Option: Mars Science Orbiter

- **Concept: Long-lived Science Orbiter Providing Atmospheric Remote Sensing and Mission Support**
- **Goals**:
  - Extend atmospheric and seasonal surface climate baseline through next decade
    - Provide improved and new (e.g., winds) profiling capabilities
  - Provide extensive global, diurnal and seasonal survey of key trace gases, including carbon-bearing compounds with implications for interior bio/geochemical processes
    - Methane and higher order hydrocarbons
    - Photochemical products, isotopes (CO, NO, etc.)
  - Synergistic with Network for both relay and atmospheric science
  - Synergistic (lower atmosphere) with 2013 Scout (upper atmosphere)
  - Provide telecom, site characterization and atmospheric monitoring for the future
- **Approach**:
  - Low-cost sounders & wide angle imagers with new microwave/sub-mm profilers
  - Provide high-resolution, high-sensitivity spectrometers for trace gas detection
  - Payload could accommodate international contributions
- **Issues**:
  - Methane detection has been controversial
  - Could be paradigm shifting, but does diverge from the current path of geologic/geochemical landed missions leading to MSR



Option: Mid-Range Rover/Prospector

- **Concept: MER-Class Rover Deployed to New Class of Sites**
- **Goals**:
  - Respond to recent discoveries showing a variety of aqueous mineral deposits and geomorphic structures reflecting water activity on Mars
  - Characterize site & prepare sample cache for possible retrieval by future MSR
- **Approach**:
  - MER-class payloads, with modest augmentation as capability allows
  - Takes advantage of latest EDL development and preserves it for MSR
    - Key is access to new sites not reachable with current MER/MSL landing error ellipses
  - Updates “Sky Crane” technology to enable precision landing (< 6 km diameter ellipse)
    - Capability needed to get to the most compelling sites
    - Capability also useful for MSR collection/rendezvous to return samples
  - Conducts (“Prospector Option”) sample selection, encapsulation and general handling needed for MSR, provides retrievable sample cache
- **Issues**:
  - Requires (modest?) improvement of EDL system
  - Prospector concept requires development of sample handling capabilities
  - Requires new EDL design for implementation (I.e., cannot use MER/MSL technologies)
  - Builds on recent discoveries, but delays broadening scope of Mars science exploration

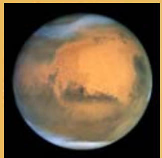


Qualitative Comparison of Candidates

	#	Investigation	MSL	MSO (atmospheric)	Network	Prospector Rover	MSR (assuming non-polar site)
HIGH	1	PRESENT STATE AND CYCLING OF WATER					
	2	SEDIMENTARY PROCESSES AND EVOLUTION					
	3	CALIBRATE CRATERING					
	4	IGNEOUS PROCESSES AND EVOLUTION					
	5	SURFACE-ATM INTERACTIONS					
	6	LARGE-SCALE CRUSTAL VERT STRUCTURE					
	7	TECTONIC HISTORY OF CRUST					
	8	HYDROTHERMAL PROCESSES					
	9	REGOLITH FORMATION AND MODIFICATION					
	10	CRUSTAL MAGNETIZATION					
LOW	11	EFFECTS OF IMPACTS					
HIGH	1	STRUCTURE AND DYNAMICS OF INTERIOR					
	2	ORIGIN AND HISTORY OF MAGNETIC FIELD					
	3	CHEMICAL AND THERMAL EVOLUTION					
LOW	4	PHOBOS/DEIMOS					
HIGH	1	DUST - ENGINEERING EFFECTS					
	2	ATMOSPHERE (EDL/TAO)					
	3	BIOHAZARDS					
	4	ISRU WATER					
	5	DUST TOXICITY					
	6	ATMOSPHERIC ELECTRICITY					
	7	FORWARD PLANETARY PROTECTION					
	8	RADIATION					
	9	SURFACE TRAFFICABILITY					
	10	DUST STORM METEOROLOGY					
	1	AEROCAPTURE					
	2	ISRU DEMOS					
	3	PINPOINT LANDING					
	4	TELECOM INFRASTRUCTURE					
	5	MATERIALS DEGRADATION					
LOW	6	APPROACH NAVIGATION					

LEGEND	
Major contribution	
Significant contribution	
2013-2016 investigations not addressed by MSR lander	

Characterizes interior structure and composition in ways not possible with MSR, MSL; atmospheric objectives leveraged by orbital remote sensing

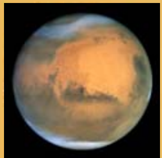


Qualitative Comparison of Candidates

				Investigation	MSL	MSO (atmospheric)	Network	Prospector Rover	MSR (assuming non-polar site)
		HIGH	1	CURRENT DISTRIBUTION OF WATER					
			2	GEOLOGIC H2O HISTORY					
			3	C,H,O,N,P, AND S - PHASES					
		LOW	4	POTENTIAL ENERGY SOURCES					
		HIGH	1	ORGANIC CARBON					
			2	INORGANIC CARBON					
			3	LINKS BETWEEN C AND H, O, N, P, S					
		LOW	4	REDUCED COMPOUNDS ON NEAR SURFACE					
		HIGH	1	COMPLEX ORGANICS					
			2	CHEMICAL AND/OR ISOTOPIC SIGNATURES					
			3	MINEROLOGICAL SIGNATURES					
		LOW	4	CHEMICAL VARIATIONS REQUIRING LIFE					
		HIGH	1	WATER, CO2, AND DUST PROCESSES					
			2	SEARCH FOR MICROCLIMATES					
		LOW	3	PHOTOCHEMICAL SPECIES					
		HIGH	1	ISOTOPIC, NOBLE & TRACE GAS COMP.					
			2	RATES OF ESCAPE OF KEY SPECIES					
			3	ISOTOPIC, NOBLE, AND TRACE GAS EVOLUTION					
			4	PHYS AND CHEM RECORDS					
		LOW	5	STRATIGRAPHIC RECORD--PLD					
		HIGH	1	THERMAL & DYNAMICAL BEHAVIOR OF PBL					
			2	ATM. BEHAVIOR 0-80 KM					
			3	ATM. MD 80-200 KM					
		LOW	4	ATM. MD >200 KM					

LEGEND	
Major contribution	
Significant contribution	
2013-2016 investigations not addressed by MSR lander	

Strong contribution to high-priority Goal II objectives not addressed by MSR; extends local MSL results spatially



Qualitative Comparison of Candidates

	Investigation	MSL	MSO (atmospheric)	Network	Prospector Rover	MSR (assuming non-polar site)
HIGH	1 PRESENT STATE AND CYCLING OF WATER					Significant
	2 SEDIMENTARY PROCESSES AND EVOLUTION	Significant			Major	Major
	3 CALIBRATE CRATERING					Major
	4 IGNEOUS PROCESSES AND EVOLUTION	Major		Significant	Significant	Major
	5 SURFACE-ATM INTERACTIONS	Significant			Significant	Major
	6 LARGE-SCALE CRUSTAL VERT STRUCTURE	Significant		Significant	Significant	Significant
	7 TECTONIC HISTORY OF CRUST		Not addressed	Major	Not addressed	
	8 HYDROTHERMAL PROCESSES	Major		Significant		Major
	9 REGOLITH FORMATION AND MODIFICATION	Significant		Significant	Significant	Significant
	10 CRUSTAL MAGNETIZATION					Significant
LOW	11 EFFECTS OF IMPACTS	Significant		Significant	Significant	Significant
HIGH	1 STRUCTURE AND DYNAMICS OF INTERIOR			Major		Significant
	2 ORIGIN AND HISTORY OF MAGNETIC FIELD			Major		Significant
	3 CHEMICAL AND THERMAL EVOLUTION	Significant		Significant	Significant	Significant
LOW	4 PHOBOS/DEIMOS		Not addressed	Not addressed	Not addressed	
HIGH	1 DUST - ENGINEERING EFFECTS	Significant			Significant	Major
	2 ATMOSPHERE (EDL/TAO)		Not addressed	Not addressed	Not addressed	
	3 BIOHAZARDS	Significant				Major
	4 ISRU WATER					Significant
	5 DUST TOXICITY					Major
	6 ATMOSPHERIC ELECTRICITY		Not addressed	Significant	Not addressed	
	7 FORWARD PLANETARY PROTECTION					Significant
	8 RADIATION	Significant	Not addressed	Significant	Not addressed	
	9 SURFACE TRAFFICABILITY		Not addressed	Not addressed	Not addressed	
	10 DUST STORM METEOROLOGY		Not addressed	Significant	Not addressed	
	1 AEROCAPTURE		Not addressed	Not addressed	Not addressed	
	2 ISRU DEMOS		Not addressed	Not addressed	Not addressed	
	3 PINPOINT LANDING		Not addressed	Not addressed	Significant	
	4 TELECOM INFRASTRUCTURE		Major	Not addressed	Not addressed	
	5 MATERIALS DEGRADATION		Not addressed	Not addressed	Not addressed	
LOW	6 APPROACH NAVIGATION		Not addressed	Not addressed	Not addressed	

LEGEND	
Major contribution	Major
Significant contribution	Significant
2013-2016 investigations not addressed by MSR lander	Not addressed

Potential to extend analytical capabilities to classes of surface deposits not measured by MSL or MER

MATT Guiding Principles (1 of 2)

MATT developed these strategic principles to guide mission architecture development:

- Conduct a Mars Sample Return Mission (MSR) at the earliest opportunity, while recognizing that the timing of MSR is budget driven.
  - Returned samples meet minimum requirements set out in the ND-SAG report
- If MSR is deferred, MEP needs to proceed with a balanced scientific program while taking specific steps toward a MSR mission
  - Immediately start and sustain a technology program to focus on specific sample return issues including, but not limited to, precision landing and sample handling
  - Address non-MSR high priority science objectives, particularly as endorsed by NRC strategies and the Decadal Survey (e.g., network)
- Conduct major surface landings no more than 4 launch opportunities apart (3 is preferred) in order to:
  - Respond to discoveries from previous surface missions and new discoveries from orbit
  - Use developed technologies and experienced personnel to reduce risk and cost to future missions, especially MSR

MATT Guiding Principles (2 of 2)

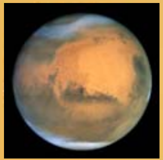
MATT developed these strategic principles to guide architecture development (cont.):

- Require that rovers preceding MSR:
  - Demonstrate sample acquisition and caching technologies that meet the minimum requirements set out in the ND-SAG report
  - Investigate new sites to explore the diversity of Mars revealed from orbit and to provide multiple options for MSR
    - This requires precision landing to access the most promising sites and to feed-forward to MSR
- Provide long-lived orbiters to observe the atmosphere and seasonal surface change, and to provide telecom and critical event support
  - Provides flexibility to MSR flight configurations and is especially synergistic with network science and telecom needs
- Scout missions are included in the architecture to provide:
  - Rapid, innovative response to new discoveries
  - Opportunity to sustain program balance and diversity
  - Low-cost Scout missions were inserted as opportunities permitted and budget profiles demanded

MATT Architecture Assessment

Specific Assumptions:

- **2013 Scout would be chosen from the current competition**
  - Scout would provide telecom for a Lander/Rover launched in 2016
- ***Mission sequences considered in order of when MSR Lander would launch (after FY16, as directed)***
  - MSR is at least a 2-element mission (lander/rover/ascent + orbiter/capture/return)
  - Generally launch MSR-O after MSR-L to give extended sample time on surface
- **2009 MSL launch => a major landed mission no later than 2018**
  - *If not MSR in 2018, substitute "Prospector" rover in 2016 or 2018*
- **Precede landed network (NET) with long-lived orbiter**
  - Synergistic both for atmospheric science and for telecom
  - MSR-O does not provide this capability
- **"Ballpark" Budget guidelines**
  - 450 M/yr or 550 M/yr(2009 $ inflated for future years)
  - Early budget constraints preclude an MSR Lander launch in 2016



Mission Scenarios

Option	2016	2018	2020[#2]	2022[#2]	2024	2026	Comments
2018a[#1]	MSR-O	MSR-L	MSO	NET	Scout	MPR	Funded if major discovery?
2018b[#1]	MSO	MSR-L	MSR-O	NET	Scout	MPR	Restarts climate record; trace gases
2018c[#1]	MPR	MSR-L	MSR-O	MSO	NET	Scout	Gap in climate record; telecom?
2020a	MPR	MSO	MSR-L	MSR-O	NET	Scout	MPR helps optimize MSR
2020b	MPR	Scout	MSR-L	MSR-O	MSO	NET	Gap in climate record, early Scout
2022a	MPR	MSO	NET	MSR-L	MSR-O	Scout	Early NET; MPR helps MSR
2022b	MSO	MPR	NET	MSR-L	MSR-O	Scout	Early NET, but 8 years between major landers (MSL to MPR)
2024a	MPR	MSO	NET	Scout	MSR-L	MSR-O	Early NET; 8 years between major landers; very late sample return

MSO = Mars Science Orbiter

MPR = Mars Science Prospector (MER or MSL class Rover with precision landing and sampling/caching capability)

MSR = Mars Sample Return Orbiter (MSR-O) and Lander/Rover/MAV (MSR-L)

NET = Mars Network Landers ("Netlander") mission

<u>FOOTNOTES:</u>

#1 Requires early peak funding well above the guidelines; 2018b most affordable of these options

#2 Celestial mechanics are most demanding in the 2020 and 2022 launch opportunities; arrival conditions (Mars atmospheric pressure, dust opacity) challenging after 2020

Preferred Scenario for given MSR-L Launch Opportunity

MATT Summary

- **High-priority science objectives can be addressed in 2016-2026 with a series of missions including, but not limited to, Mars Sample Return (MSR)**
  - *Early sample return is preferred as the findings are likely to affect profoundly future Mars exploration*
- **An MSR-L launch in 2018--desired scientifically--significantly exceeds funding guidelines as early as FY15-17**
  - If early funding provided [unlikely], MSO goes in 2016 to provide mission support and to restart the climatology record measurements prior to MSR *[Option 2018b]*
- ***If an MSR-L launch is deferred until after 2018, MATT finds two near-term mission architectures to be scientifically compelling, while providing real progress towards an MSR. Furthermore, these two scenarios have the same initial mission set for 2016 and 2018:***

  Now: Start technology program focused on developments that enable MPR and feed-forward to MSR

  2016: Launch Mars Prospector Rover (MPR) to a new site

  2018: Launch Mars Science Orbiter (MSO) for long-lived observations and telecom support for science

  Option 2020a: Launch MSR-L in 2020 followed by NET in 2024

  Option 2022a: Launch MSR-L in 2022 preceded by NET in 2020

  -Earlier MSR option preferred

MATT Notes

- **Note #1: Major discoveries by ongoing or near-term missions (PHX, MSL, ExoMars) may change the architecture assessment**
  - For example, a PHX discovery may motivate a high-latitude lander with vertical access
  - Response depends on nature of discovery--no attempt was made here to map out a “response tree” to the many possible discoveries that could be made
  - *The current operating missions are fully capable of making major new discoveries and their observation programs should be extended and data analysis supported*

- **Note #2: Many missions considered here are well-suited to international participation and partnering**
  - Prime examples for major subsystems or flight elements are MSR and Network
  - Opportunities for payload participation exist for MPR and MSO

Back-Up

Guidelines for the MATT-2 Study

- **Assumptions**:
  1. Telecommunications infrastructure, site selection, and critical event coverage, early in the next decade, should not be a concern of MATT for this study. In other words, look at the science that is desired and assume the rest will follow.
  2. Assume the MEP budget is sustained at some rate (~$550M/yr beginning in 2010) and trades can be made in peak spending years.
  3. The 2016 mission could cost ~$1B
  4. Last element of MSR is launched in 2022

- **Possible Considerations**:
  1. Proper caching of samples should be done on any future landed opportunity
  2. Possible role of virtual caching (i.e., sampling sites are characterized but samples are not cached)
  3. Two MER class rovers instead of one rover for sample caching.
  4. ESA may have a 2016 orbiter, for testing rendezvous and capture, and for delivery of small landers to the surface
  5. Could/should two rovers be built simultaneously, and then each rover launched independently (either in the same of separate opportunities)
  6. Inform and solicit comments from the community, perhaps through an accompanying MEPAG announcement
  7. Possible Scout in 2018

MATT Response to the Questions

Propose a Mars exploration architecture(s) that will optimize the science return within fiscal and programmatic constraints.

Scenarios 2020a and 2022a

1. Is the proposed MSR the highest priority for the Mars science community, assuming the cost constraint listed below?

   MSR is the highest priority for this decade and should be conducted at the earliest opportunity; however, it would require additional (peak) funding above the cost guidelines, no matter when it occurs; international partnering can help

2. Given that the 2016 opportunity is too early for the launch of either of two elements of the proposed MSR, what should be the 2016 mission?

   MPR in 2016 followed by MSO in 2018 if MSR-L is launched after 2018

3. Can the proposed MSR be split between more than two flight elements to reduce peak costs in any fiscal year?

   Development and demonstration of precision landing and sample selection/caching will reduce risk and demonstrate progress towards sample return, but the MSR cost savings is modest even when MPR is a critical path element in MSR

4. What is the architecture if there is no sample return in the foreseeable future?

   Proceed with 2022a